Executive Summary

The Colorado River is the principal source of water for agricultural, domestic, municipal, industrial, recreational, and hydroelectric purposes in Arizona, southern California, and southern Nevada. Within this area, accounting for the use and distribution of water from the lower Colorado River is required by the U.S. Supreme Court Decree of 1964 (Supreme Court Decree) in *Arizona* v. *California*. In addition to its other requirements, the Supreme Court Decree dictates that the Secretary of the Interior (Secretary) provide detailed and accurate records of diversions, return flows, and consumptive use of water diverted from the mainstream "stated separately as to each diverter from the mainstream, each point of diversion, and each of the States of Arizona, California, and Nevada." This report focuses on determining values of consumptive use.

The Bureau of Reclamation (Reclamation) manages the water resources of the lower Colorado River on behalf of the Secretary. In 1984, Reclamation joined with the U.S. Geological Survey (USGS), Arizona, California, and Nevada (Lower Basin States), and Bureau of Indian Affairs to develop a method for estimating and distributing agricultural consumptive use to agricultural[1] water diverters between Hoover Dam and Mexico. This effort was in response to the Lower Basin States' request to account for return flows in addition to those measured as surface flows, a limitation of the water accounting method then in use.

The agencies agreed to develop the lower Colorado River Accounting System (LCRAS), which addresses the requirements of the Secretary and responds to the Lower Basin States' request to account for both measured and unmeasured flows. The USGS finished its development of LCRAS in the late 1980s, but a final report was not published until 1995. In 1990, Reclamation took over responsibility for continuing development of LCRAS. Reclamation has modified LCRAS and issued a report in 1995 entitled "Lower Colorado River Accounting System Demonstration of Technology for Calendar Year 1995" (1995 LCRAS report), which documents the first application of this modified version of LCRAS. This report also contains a more detailed history of events which led to the development of LCRAS. This report documents the application of LCRAS to calendar year 1996 and the changes made to the LCRAS method made since the 1995 LCRAS report was issued.

[1] Agricultural consumptive use includes consumptive use by irrigation districts, wildlife refuges, and other reservations of land (5 acres or more). All other consumptive uses are domestic consumptive uses.

The LCRAS Method

LCRAS is an accounting method that estimates and distributes consumptive use to diverters along the lower Colorado River. LCRAS uses a water balance equation in which all the inflows, outflows, and water uses are calculated or estimated. The residual of this water balance (residual) reflects errors of estimate in all inflows, outflows, and water uses. The residual is distributed to all inflows, outflows, and water uses in the water balance in proportion to the product of their magnitude and variance (the square of the standard error of estimate, see Lane 1998).

Consumptive use by vegetation is equal to the evapotranspiration (ET) plus a proportion of the residual. The consumptive use by vegetation can be either slightly larger or smaller than the ET, and the consumptive use of domestic users can be slightly larger or smaller than initially estimated for the water balance because the residual can be either a positive or negative number.

ET is estimated using (1) reference values for short grass (ET_0) provided by the California Irrigation Management Information System and Arizona Meteorological Network stations located in agricultural areas along the Colorado River, (2) vegetation-class-specific ET coefficients, and (3) acres of each crop and phreatophyte class that appeared along the lower Colorado River developed from the classification of remotely sensed data (image classification). Domestic uses are initially estimated by applying a consumptive use factor to a measured diversion (usually 0.6), or by applying a per-capita consumptive use factor to a population (usually 0.14 acre-feet per year per capita if turf irrigation is not significant), or by subtracting a measured return flow from a measured diversion, or, in a few cases, by a method submitted by a domestic user.

Results

LCRAS calculates both agricultural and phreatophyte consumptive use for each agricultural diverter and wildlife refuge, and domestic consumptive use for each domestic diverter along the mainstream of the lower Colorado River. The amount, if any, of the phreatophyte consumptive use within a diverter's boundary that should be added to a diverter's total consumptive use is a question left open by this report.

A description and qualitative assessment of the results for the major components of LCRAS follows.

Image Classification Results

The image classification results show excellent results using Landsat V image data to discriminate agricultural vegetation classes. Reliable results were obtained for crops using single-date image classification processes. Post-classification accuracy assessment shows that, overall, the crops can be mapped with an average accuracy of approximately 93 percent for each image classification date (4 dates per year) in 1996.

Discrimination between phreatophytes, while not as well defined as crops, was successful. Phreatophytes were grouped into several classes. The phreatophyte communities database was updated in 1996 using remote-sensing-based change detection methodologies and the 1995 phreatophyte database. Accuracy assessment of updated maps is planned for 1997.

Image classification processes were also used to quantify open water surface areas. Open water surface areas for reservoirs derived from image classification processes were compared with the equivalent values derived from published elevation/capacity/area tables in 1995. This comparison showed the open water surface areas derived from the two methods to be within 3 percent of each other. This comparison was not repeated for 1996.

Water Balance Results

The water balance closure was evaluated for each reach by comparing the value of the residual to the measurement error of the upstream inflow to the reach. A second measure of water balance closure, used in 1996, is the magnitude of the final adjustments to the flows at the major dams and the flow to Mexico which define the upstream and downstream flows for each reach.
Distributing the residual is considered optional if the value of the residual is about equal to or less than the presumed measurement error of the flow entering the reach. The residual was distributed in all reaches for 1996 to present the effect of the distribution,

even though the residual was about equal to or less than the presumed measurement error of the upstream gauge in three of the four reaches.

The standard error of estimate values for the upstream flows for each reach is 1.4 percent for Hoover Dam, 2.2 percent for Davis and Parker Dams, and 1.5 percent for Imperial Dam.

Table ES-1 presents the values used in the water balance and shows the closure of the water balance.

Table ES-1.—Water balance summary (unadjusted for residual)
(Unit: acre-feet per year unless otherwise noted)

Water balance inflows, outflows, and water uses	Reach				
	Hoover Dam to Davis Dam	Davis Dam to Parker Dam	Parker Dam to Imperial Dam	Imperial Dam to Mexico	Hoover Dam to Mexico
Flow at the upstream boundary (Q_{us})	9,972,100	9,931,500	7,300,500	6,106,432	9,972,100
Flow at the downstream boundary (Q_{ds})	9,931,500	7,300,500	6,106,432	1,587,334	1,587,334
Residual	-62,469	-198,208	14,051	142,625	-104,001
Residual as a percentage of the flow entering the reach (Q_{us})	-0.63%	-2.00%	0.19%	2.34%	-1.04%
Difference between upstream and downstream flow (Q_{dif})	40,600	2,631,000	1,194,068	4,519,098	8,384,766
Measured Tributary inflow (Trm)	0	3,527	0	9,406	12,933
Unmeasured Tributary inflow (Trum)	6,480	45,090	33,750	3,000	88,320
Exported flow (Q_{ex})	0	2,423,342	0	3,857,084	6,280,426
Evaporation (E)	148,638	130,673	63,100	11,073	353,484
Domestic consumptive[1] use (C_{ud})	393	38,982	4,657	29,968	74,000
Crop evapotranspiration (ET_{crop})	0	87,370	745,101	412,947	1,245,418
Phreatophyte evapotranspiration (ET_{pht})	12,118	196,358	395,459	77,807	681,742
Change in reservoir storage (ΔS_r)	-51,600	1,100	5,450	0	-45,050
Change in aquifer storage (ΔS_a)	0	0	0	0	0

[1] Domestic consumptive use includes all non-agricultural consumptive uses.

Consumptive Use Results

Table ES-2 compares the crop, phreatophyte, and domestic consumptive use calculated by LCRAS to consumptive use as reported in the Decree Accounting Report as State totals.

Table ES-2.—Consumptive use
(unit: acre-feet per year)

LCRAS			Decree Accounting	
Diverter name	Phreatophyte consumptive use	Crop and domestic consumptive use	Consumptive use	Diverter name
Nevada				
Uses above Hoover Dam (from 1996 Decree Accounting Report)		231,400	231,400	Uses above Hoover Dam
Uses below Hoover Dam	29,443	17,704	17,847	Uses below Hoover Dam
			746	Unmeasured return flow credit
Nevada Total	29,443	249,104	248,501	Nevada Total
California				
	213,653	5,202,985	5,322,653	Sum of individual diverters
			96,487	Unmeasured return flow credit
California Total	213,653	5,202,985	5,226,166	California Total
Arizona				
Subtotal (below Hoover Dam, less Wellton-Mohawk IDD)	438,686	2,137,685	2,497,656	Sum of individual diverters below Hoover Dam, less Wellton-Mohawk IDD and returns from South Gila wells
Arizona uses above Hoover Dam (1996 Decree Accounting Report)		188	188	Arizona uses above Hoover Dam
Wellton-Mohawk IDD (1996 Decree Accounting Report)		274,421	274,421	Wellton-Mohawk IDD
			57,368	Pumped from South Gila wells (drainage pump outlet channels [DPOCs]): returns
			161,955	Unmeasured return flow credit
Arizona Total	438,686	2,412,294	2,552,942	Arizona Total
Lower Basin Total				
Total Lower Basin Use	681,782	7,864,383	8,027,609	Total Lower Basin Use

Table ES-3 shows the final adjusted values of all the water balance components after the residual has been distributed, and after the flows at the major dams and the flow to Mexico, which form the upstream and downstream boundaries of the reaches, have been adjusted as described in Lane 1998.

Table ES-3.— Final distributed and adjusted water balance values
(units: acre-feet per year)

Water balance inflows, outflows, and water uses	Reach				
	Hoover Dam to Davis Dam	Davis Dam to Parker Dam	Parker Dam to Imperial Dam	Imperial Dam to Mexico	Hoover Dam to Mexico
Flow at the upstream boundary (Q_{us})	10,114,702	10,011,692	7,189,509	6,008,755	10,114,702
Flow at the downstream boundary (Q_{ds})	10,011,692	7,189,509	6,008,755	1,573,204	1,573,204
Residual	0	0	0	0	0
Difference between upstream and downstream flow (Q_{dif})	103,010	2,822,183	1,180,754	4,435,551	8,541,498
Measured Tributary inflow (Trm)	0	3,550	0	9,402	12,952
Unmeasured Tributary inflow (Trum)	6,484	45,566	33,710	2,993	88,753
Exported flow (Q_{ex})	0	2,417,235	0	3,912,066	6,329,301
Evaporation (E)	148,587	130,562	63,104	11,076	353,329
Domestic consumptive[1] use (C_{ud})	393	38,980	4,657	29,971	74,001
Crop consumptive use (CU_{crop})	0	87,320	745,642	416,886	1,249,848
Phreatophyte consumptive use (CU_{pht})	12,118	196,107	395,611	77,947	681,783
Change in reservoir storage (ΔS_r)	-51,604	1,095	5,450	0	-45,059
Change in aquifer storage (ΔS_a)	0	0	0	0	0

Continued Development of LCRAS

LCRAS used the best and most complete data sources and analytic techniques available to produce the results presented in this report; however, improvements are possible, and some questions remain outstanding.

Specific areas identified for continued development include remote sensing, image processing, and geographic information system analysis tools; river gauging; incidental

use factors in crop ET calculations; open water surface evaporation and precipitation estimates; the appropriate assessment of phreatophyte use, if any, to diverters; and a method of estimating changes in groundwater storage.

Conclusions

Reclamation is directed to manage the lower Colorado River. Currently, the demand for water exceeds the 7.5 million acre-feet apportioned for annual consumptive use. Because of the scarcity of this resource, Reclamation must manage the river in a manner that is fair for all diverters. To achieve this goal, Reclamation has taken the lead in the development of LCRAS, which can be characterized as a water accounting method that meets the following criteria:

- Uses the best technology available
- Fulfills the Supreme Court Decree mandate to account for the consumptive use of water
- Provides consistent methods of determining water use for all diverters in the lower Colorado River basin

The goal of the LCRAS program is to improve the Decree Accounting Report using state-of-the-art technologies. Reclamation will continue the process of refining each element of LCRAS as technology develops and our understanding of the hydrologic system improves.

Reclamation is currently participating in a public process which provides interested parties an opportunity to learn more about the method and provide input to improve it. Reclamation is interested in working with the State water agencies, Federal agencies, tribes, and diverters to make the method as consistent, accurate, and understandable as possible.

The accounting of water use in accordance with Article V of the Supreme Court Decree will proceed over the next few years as follows:

1. Reclamation will use the current Decree Accounting method to develop the official Decree Accounting Report until LCRAS is implemented.

2. Reclamation will calculate consumptive use using the LCRAS method in parallel with the current Decree Accounting method for calendar year 1997 and the next several years and compare the results of the two methods. The purpose of this exercise is to acquaint the users of the Decree Accounting Reports with LCRAS, as well as to examine any trends that may appear in the differences of the results provided by the two methods.